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Airframe Noise of a Small Model Transport Aircraft and Scaling Effects

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SUMMARY

Airframe noise of a 0.01-scale model of the Boeing 747 wide-body transport has been measured in the Langley Anechoic Noise Facility. The model geometry simulated both the landing and cruise configurations. The model noise was found to be similar in characteristics to that generated by a 0.03-scale-model 747 tested in a different facility and was a function of the leading- and trailing-edge flap systems. The 0.01-scale-model noise data scaled to within 3 dB of full-scale data using the same scaling relationships as were used for the 0.03-scale-model noise data. The 0.01-scale-model noise data compared to within 3 dB of full-scale data that were calculated using the NASA Aircraft Noise Prediction Program (ANOPP).

INTRODUCTION

Airframe noise can be defined as all the noise generated by an aircraft in flight other than that associated with the aircraft propulsion system. It is comprised of the noise resulting from external flow over the fuselage, wing and tail surfaces, as well as the aircraft flap and landing gear systems. As such, it is not readily amenable to theoretical analysis. Consequently, to understand the sources of airframe noise, experimental investigations have been conducted. Various authors have studied isolated airfoils in flow facilities (ref. 1). Some researchers have measured airframe noise of full-scale aircraft and developed empirical equations to describe the noise data (refs. 2 and 3). Others have investigated small complete models with undercarriage and flap systems. The models studied included a 0.015-scale advanced supersonic transport (ref. 4), a 0.03-scale Boeing 747 transport (ref. 5), and a two-dimensional wing-flap and landing gear system (ref. 6).

The previous 747 investigation (ref. 5) yielded a scaling relationship for airframe noise spectra obtained by comparing the model data with full-scale flyover data. In that study, turbulent boundary-layer flow was induced over the model. This artificially induced turbulent environment may affect the applicability of acoustic data obtained using a small-scale model in lieu of the actual full-scale situation. Hence, a study was undertaken to investigate the applicability of the existing scaling laws to smaller models.

This report presents the results of an airframe noise experiment using a 0.01-scale 747 complete model. The purpose of the tests was to determine quantitatively the airframe noise levels of a 0.01-scale 747 model and compare the results with the results obtained from a 0.03-scale 747 model and a full-scale 747 in order to verify the scaling laws proposed for airframe noise in reference 5. The tests were conducted at the Langley Aircraft Noise Reduction Laboratory in the Anechoic Noise Facility. The model was equipped with leading- and trailing-edge flaps. The components were extended individually and collectively to ascertain their contributions to the noise field over that produced by the fuselage and the wing. Acoustical data are presented which include one-third

octave band spectra when the model is in the overhead position, and directivity in both the flyover and sideline planes for the landing configuration.

SYMBOLS

f	frequency, kHz
R	overhead observer distance, m
V	velocity, m/s
θ	flyover angle, deg
ϕ	sideline angle, deg

Subscripts:

fs	full scale
m	model

Abbreviations:

OASPL	overall sound pressure level
SF	scale factor
SPL	sound pressure level

DESCRIPTION OF MODEL AND EXPERIMENTAL METHOD

Model

The test model was a 0.01-scale-model Boeing 747 wide-body transport aircraft. The fuselage was made of wood and the wing was made of aluminum. The model had an overall length of 0.69 m and a sweptback tapered wing with a span of 0.60 m. The model was equipped with engine nacelles, nose gear, wing and main body landing gears, wheel wells, leading-edge flaps, and trailing-edge flaps. Figure 1 is a photograph of the underside of the model. The configuration tested represented that used in the normal 747 landing approach conditions with the flaps at 30°. The flap systems were made of steel to allow detail and insure exactness of shape resulting in the desired local aerodynamic environment. Figure 2 is a close-up view of the trailing-edge flap system showing fine structural detail. The appropriate wheel well doors projected into the flow when the landing gears were extended. A transition strip of fine carbide grit was applied to the leading 10 percent chord across the full wing span for all tests in order to insure a turbulent boundary layer. A force balance was used to evaluate the model lift system and to insure aerodynamic similarity with the model used in reference 5.

Test Setup and Procedure

Figure 3 shows the model mounted in the Langley Anechoic Noise Facility. The anechoic room was 6.1 by 9.1 by 7.1 m high and had 0.84-m-deep acoustical wedges on the walls and ceilings. Portable wedges were placed over the floor prior to acoustical testing. The model was sting mounted and was positioned in a nose-down attitude. The sting entered the model 1.52 m above the jet exit and provided an angle of attack of 8.75° (the angle between the flow and the model center lines). This was the angle which produced a lift coefficient of the model that approximated that of the 747 in the landing configuration. Airflow was provided by a 1.22-m-diameter vertical jet nozzle (not visible in the photograph), driven by a centrifugal fan that was housed in another building to help minimize background noise. Tests were run over a range of velocities of 20, 25, and 30 m/s. Figure 4 shows a schematic of the test setup.

Instrumentation

Acoustical data were taken with six 1/4-in. condenser-type microphones. Six microphones were mounted on poles at a height corresponding to the model-sting attachment point, in angular increments of 8°, and were used to measure sideline directivity. Microphone 1 (see fig. 4) was mounted on a vertical traversing mechanism, which provided directivity data in the flyover plane. The microphones were placed approximately 2 1/2 span lengths from the model and out of the flow. All acoustical data were high-pass filtered at 1250 Hz, and one-third octave band data were obtained on-line over a frequency range to 40 kHz.

Test Environment

The model was positioned over the jet nozzle such that the entire model was in the potential core of the jet and acoustic reflections from the jet nozzle were minimized. Based on previous hot-wire surveys, the jet was known to spread like a classical subsonic jet with the potential core extending 6 nozzle diameters downstream and to have a uniform mean flow. The jet core had turbulence levels of approximately 0.5 percent, which were sufficient for simulating conditions of a flight in atmospheric conditions.

In this study both the noise source and microphones were in fixed positions while the tests were being conducted. Thus, the shear layer effects (refraction of convected acoustic rays) on the acoustic rays were calculated using the method described in reference 7. This method models the shear layer as an infinitely thin vortex sheet. At all flow velocities, the corrections for amplitude and direction of the acoustic rays were small (less than 1/2 dB and 2°, respectively). Hence, no corrections were applied to the data presented.

RESULTS AND DISCUSSION

Presented and discussed in this section of the paper are results of airframe noise of individual extended airframe components and the landing approach configuration with the model 747 in the overhead position. Comparisons are also made of acoustic results obtained by scaling 0.01-scale- and 0.03-scale-model airframe noise data to full-scale 747 airframe noise data. The 0.01-scale-model data are also compared with calculated full-scale noise data for the landing configuration.

Background Noise Spectra

Noise spectra of the flow facility at velocities of 20, 25, and 30 m/s were recorded with the sting in place, but without the model installed. This was used as background noise and was subtracted from all corresponding model data. After the background noise was subtracted from the noise data obtained with the model in the cruise configuration, the total noise was too small to be sure that it was pure airframe noise. The results of this test are shown in figure 5. This test was the only one in which the total noise was not well above (5 to 10 dB) the background noise over the frequency range of the investigation.

Component Noise Spectra

Nacelle noise.- A series of tests were conducted to determine the effects of the engine nacelles on the noise spectra. The nacelles were tested both plugged and open. The open nacelles produced tones corresponding to that of a pipe with open ends, which was not a realistic representation for a jet engine. Thus, to eliminate the tones all the tests were performed using plugged nacelles.

Flap system.- Figure 6 shows the one-third octave band airframe noise spectra for the model in the overhead position due to the extension of the model leading-edge flaps for three velocities. The peak sound pressure level occurred at higher frequencies with increased velocity; this is also observed for the conditions where the trailing-edge flap is extended alone and the leading- and trailing-edge flaps are extended jointly and can be seen in figures 7 and 8, respectively. This velocity dependency has been observed in other airframe noise studies (refs. 1, 4, 5, and 6). Figure 9 shows a comparison of the one-third octave band airframe noise spectra attributed to the leading-edge flaps alone, the trailing-edge flaps alone, and the combination of the two systems at a velocity of 30 m/s. The leading-edge flaps generate a higher noise level in the lower frequencies than the trailing-edge flaps. In the higher frequency range the trailing-edge flaps are the primary noise source. This observation agrees with the results of reference 5. The third spectrum in figure 9 shows the measured combined effect of the two flap systems.

Landing gear system.- The landing gear system components were extended individually and as a complete system. The landing gear noise did not produce any significant change in the noise level over that of the fuselage and wings for the frequency range of the investigation.

Landing Approach Configuration

Spectra.- One-third octave band airframe noise spectra for the landing approach configuration, measured at the overhead position and the three test velocities, are presented in figure 10. The sound pressure level and peak frequency are observed to be a function of velocity. Figure 11 shows a comparison of the one-third octave band spectrum of the combined leading- and trailing-edge flaps system extended and for the landing configuration. These spectra are taken at the overhead position and at a flow velocity of 30 m/s. The spectra are basically the same except at the lower frequencies where the noise from the landing configuration is greater. Although the noise due to the landing gear system alone was not measurable above the noise of the cruise configuration, this additional noise is believed to be due to the wake from the wing landing gear system impinging on the trailing-edge flap system. This phenomenon was also observed in references 5, 8, and 9.

Directivity.- The directivity patterns of the landing approach configurations, at a flow velocity of 30 m/s, in both the flyover and sideline planes are shown in figure 12 with the data adjusted for constant radius. The flyover noise radiation produces a maximum overall sound pressure level in the forward quadrant. This forward-projected noise level increase is believed to be primarily a result of the extended trailing-edge flaps, as similar results have been observed with varying flap deflections (refs. 4 and 9).

Sideline directivity measurement for the landing configurations revealed a nearly uniform noise pattern, which has been reported previously from full-scale flyover data (refs. 3 and 9). The sideline noise was found to be primarily due to the leading- and trailing-edge flaps. This is seen in figure 13 where the airframe noise spectrum for each microphone in the sideline plane is shown. There is a common frequency range of 9 to 13 kHz for peak SPL for each microphone with a flow velocity of 30 m/s. Using the leading-edge-flap chord and the trailing-edge-flap chord, ranges of Strouhal number were calculated, respectively, that were not inconsistent with those obtained in reference 6.

Scaling of Data

The scaling relationship for the sound pressure level defined in reference 5 involves a function of velocity raised to the fifth power. In order for this relationship to be applicable to the subject data, the data must first collapse when normalized to velocity to the fifth power V^5. Figure 14 shows the variation of overall sound pressure level and velocity, with the model in the landing configuration and at the overhead position. These data fit a line for a fifth-power function. Also, figure 15 shows the collapsing of the model data which were normalized using 50 log $V_m/20$. These two figures indicate that the 0.01-scale-model data should scale according to the relationship given in reference 5.

The full-scale flyover data used in the present paper are taken from reference 5. For comparison with these data, the model data were normalized to full scale using overhead observer distance R as 112.8 m, velocity V as 76.2 m/s, and a scale factor SF of 0.01. The sound pressure level and frequency data

used for comparison were calculated using the model data and the following equations taken from reference 5:

$$SPL_{\text{scaled to f.s.}} = (SPL)_m + 10 \log \left[\left(\frac{76.2}{V_m} \right)^5 (SF)^{-2} \left(\frac{R_m}{112.8} \right)^2 \right]$$

and

$$f_{fs} = f_m (SF) \frac{76.2}{V_m}$$

where full-scale frequency f_{fs} is in hertz.

Figure 16 shows a comparison between the noise spectra of the aircraft and the model with only the leading-edge flaps extended. For the entire frequency range shown, the data agree within 3 dB of the full-scale data. The maximum scaled frequency is approximatley 1000 Hz, which corresponds to approximately 40 kHz for the model. This was the upper frequency limit of the instrumentation system used for these tests. The necessity of obtaining noise data at high frequency in order to scale adequately to full scale is one prohibiting factor when using a very small model for measuring airframe noise. Another, of course, is the great difficulty experienced in manufacturing a small model with exactness.

The comparison of noise spectra for the 0.01-scale model and full-scale aircraft with only the trailing-edge flaps extended is shown in figure 17. The scale model data are in agreement with the full-scale data. In reference 5 there was some disagreement in this comparison for the 0.03-scale-model data and the full-scale data. However, the 0.01-scale-model trailing-edge flap system was modeled very accurately, and this accuracy is believed to be the contributing factor for achieving the good results shown in figure 17.

Figure 18 shows the results obtained for the 0.01-scale-model data scaled to full scale with both the leading- and trailing-edge flaps extended. These data agree across the entire measured frequency range, indicating that there was little if any flow interaction among the leading- and trailing-edge flaps or there was interaction and it scaled accordingly.

Figure 19 presents a spectra of the 0.01-scale-model data scaled to full-scale data in the landing configuration. These data agree within 3 dB of the full-scale data except at the lower frequency range. This disagreement is believed to be due to the flow effects of the landing gear system on the trailing-edge flaps not scaling using the proposed relationships. It is realized that the flow field is complex and these results indicate that Reynolds number may affect scaling of airframe noise for bluff bodies. These component interaction effects have been observed before and are reported in references 5,

6, and 8. The basic problem is in obtaining the noise spectra contributed by these bluff bodies, since they usually exist below the background noise spectra of the flow facility.

Comparison of 0.01-Scale- and 0.03-Scale-Model Data

Figure 20 shows the comparison of 0.01-scale- and 0.03-scale-model data, obtained in different facilities, scaled to full-scale data. The 0.03-scale-model data were taken from reference 5. Both models had leading- and trailing-edge flaps extended, and the models were in the overhead position. The figure shows excellent agreement of the model data when scaled to full scale using the scaling relationship from reference 5.

Comparison With Prediction Method

To further evaluate the scaling laws presented in reference 5, one-third octave band full-scale airframe sound pressure levels were calculated using the NASA Aircraft Noise Prediction Program (ANOPP) described in reference 10. This program incorporated the aircraft component (flaps, wheels, etc.) method prediction scheme described in reference 11. A comparison of the prediction method and the scaled airframe noise data from the 0.01-scale model is shown in figure 21. The scaled model airframe noise data agree within 3 dB of the calculated data over the scaled frequency range of the investigation, with a slight underprediction of the full-scale data across the entire spectrum.

CONCLUDING REMARKS

Results have been presented from airframe noise tests conducted on a 0.01-scale model of a 747 wide-body transport in the Langley Anechoic Noise Facility. The 0.01-scale model had airframe noise spectra similar to those of the 0.03-scale model previously reported in AIAA Paper No. 77-57. The airframe noise level was found to be a function of the leading- and trailing-edge flap systems. The leading-edge flap system dominated at the lower frequency range reported and the trailing-edge flap system dominated at the higher range. The landing gear noise spectra could not be detected above the background noise. For the cruise configuration the airframe noise spectrum was not completely detectable over the background noise. Results show that the airframe noise directivity pattern of the landing configuration in the flyover plane could be due primarily to the deflected trailing-edge flaps, and the overall sound pressure level peaked in the forward quadrant. The sideline airframe noise directivity pattern was found to be due to both the extended leading-edge flaps and trailing-edge flaps. Results also show that independent of the model size the scaled

sound pressure level was directly proportional to the fifth power of the flow velocity and inversely proportional to the square of the distance from the source to the microphone. The scaled frequency was concluded to be directly proportional to the velocity.

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April 3, 1981

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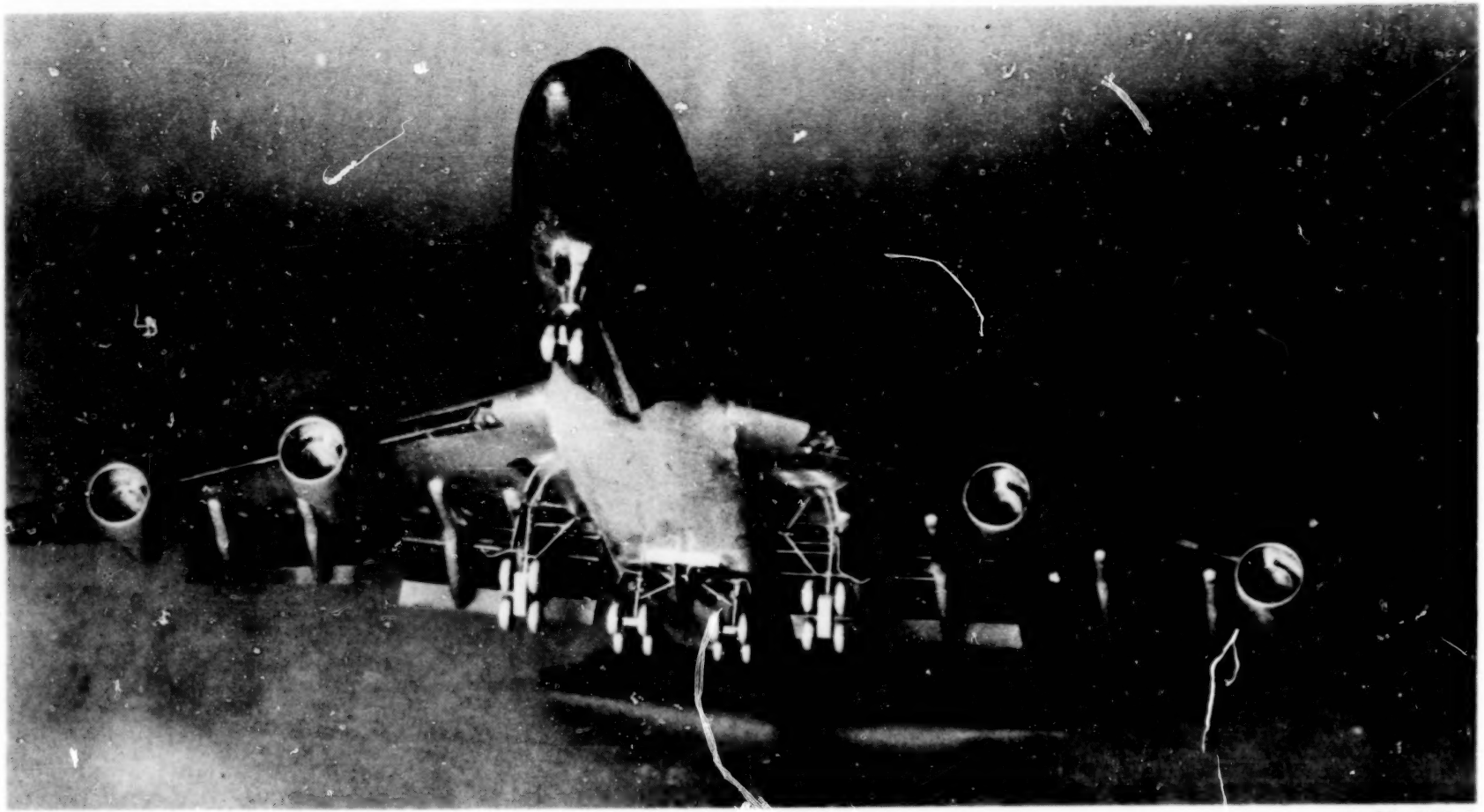

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Figure 1.- 0.01-scale model.

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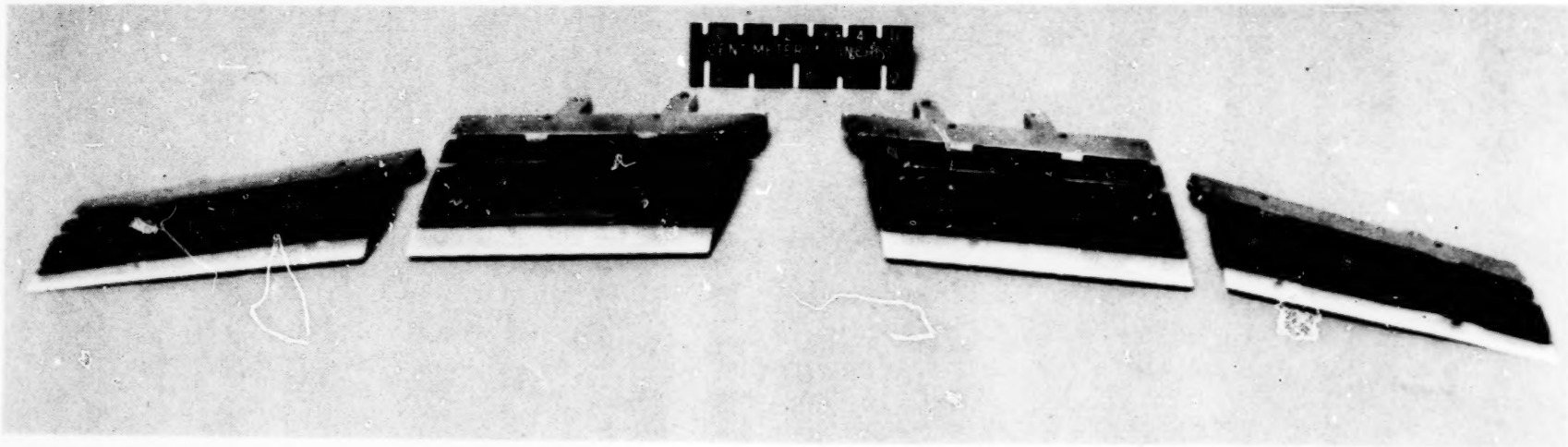

Figure 2.- Trailing-edge flap system.

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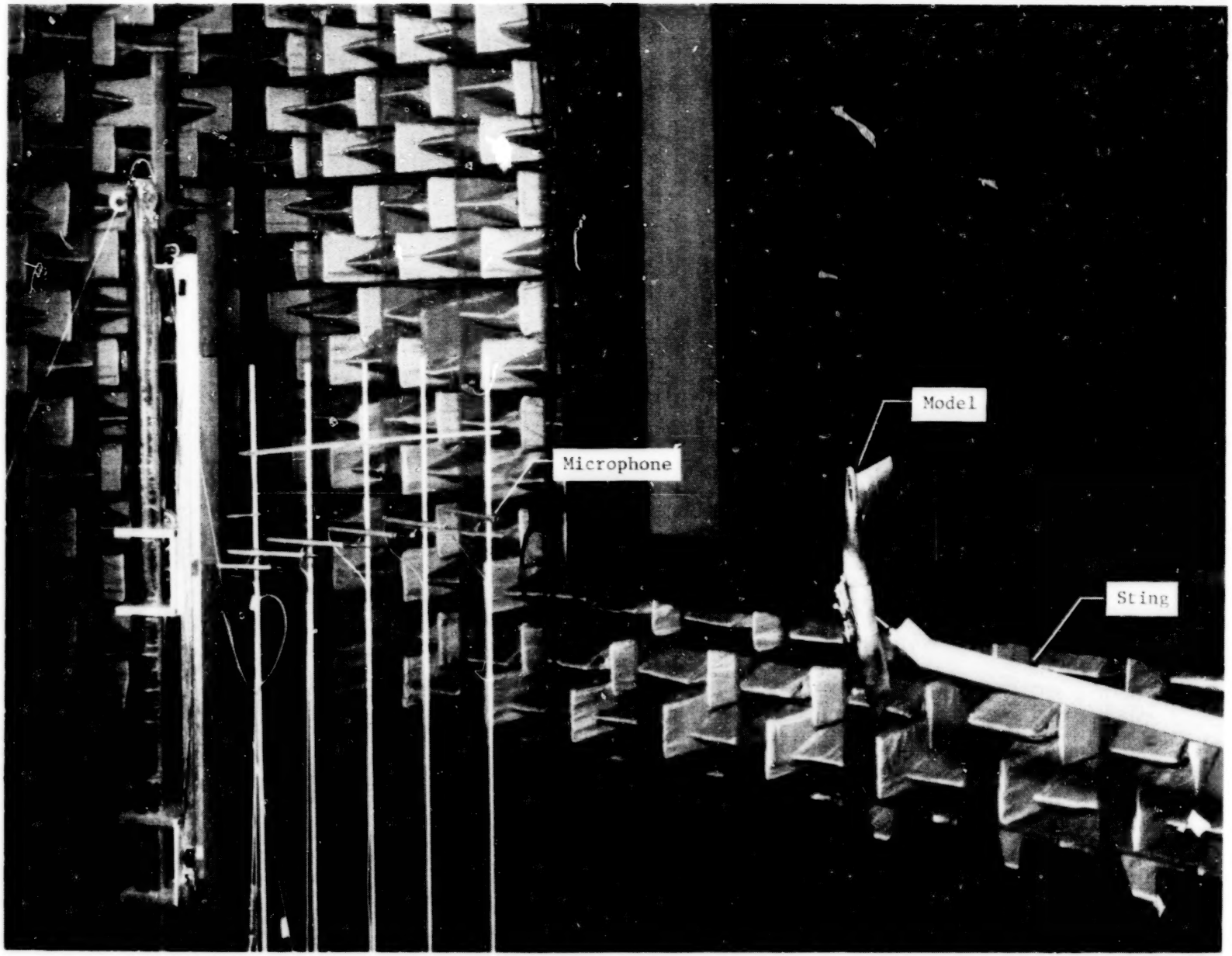

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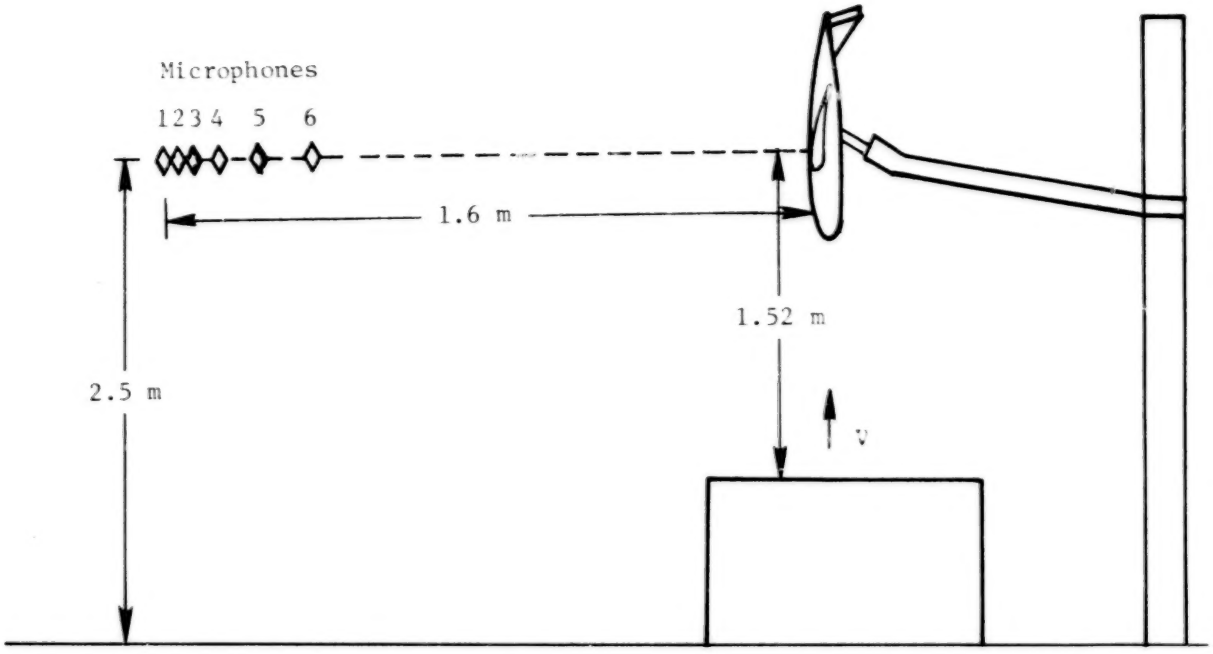
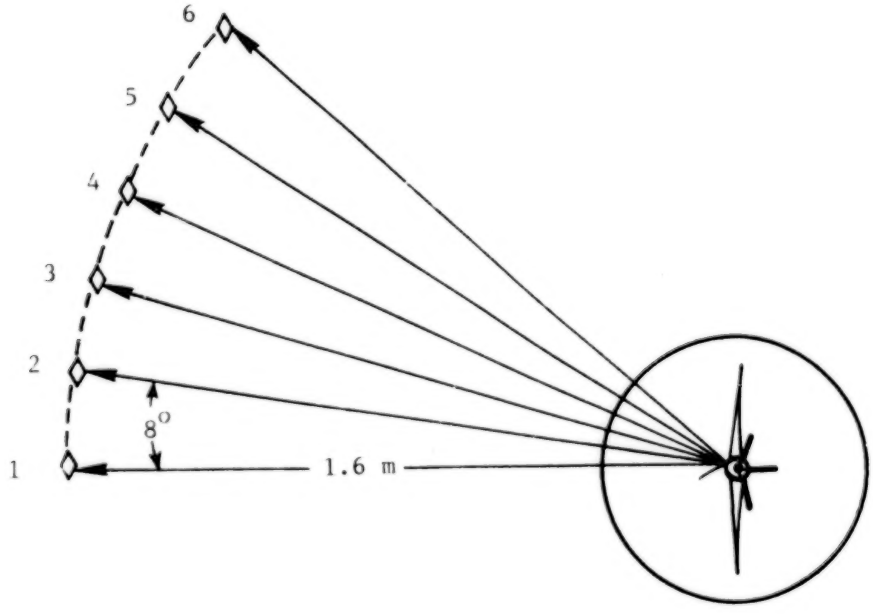
Figure 3.- Model in Langley Anechoic Noise Facility.



(a) Profile view.



(b) Plan view.

Figure 4.- Schematic of test setup.

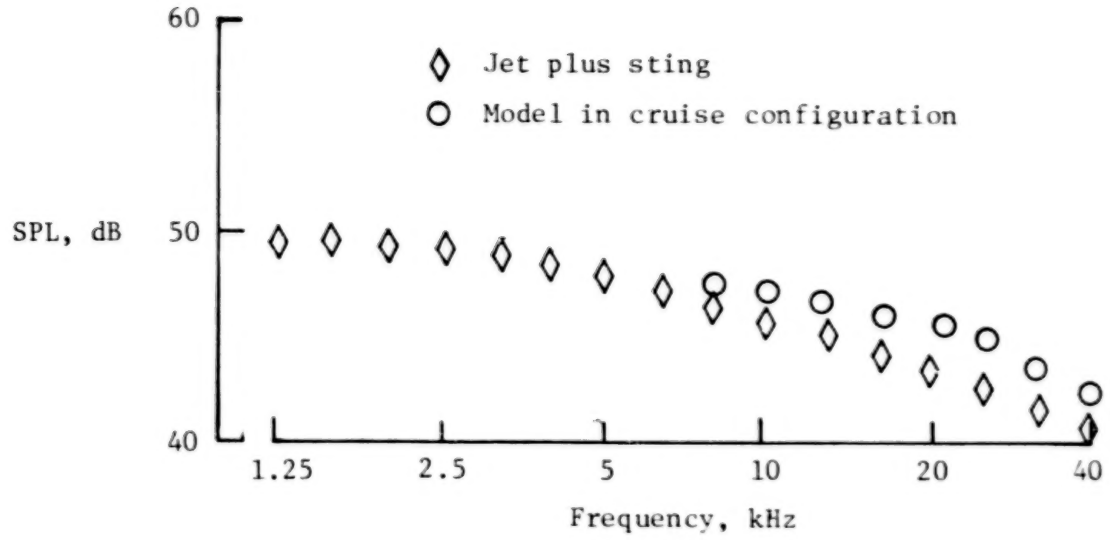


Figure 5.- One-third octave band spectra of background noise and model in cruise configuration. V = 30 m/s.

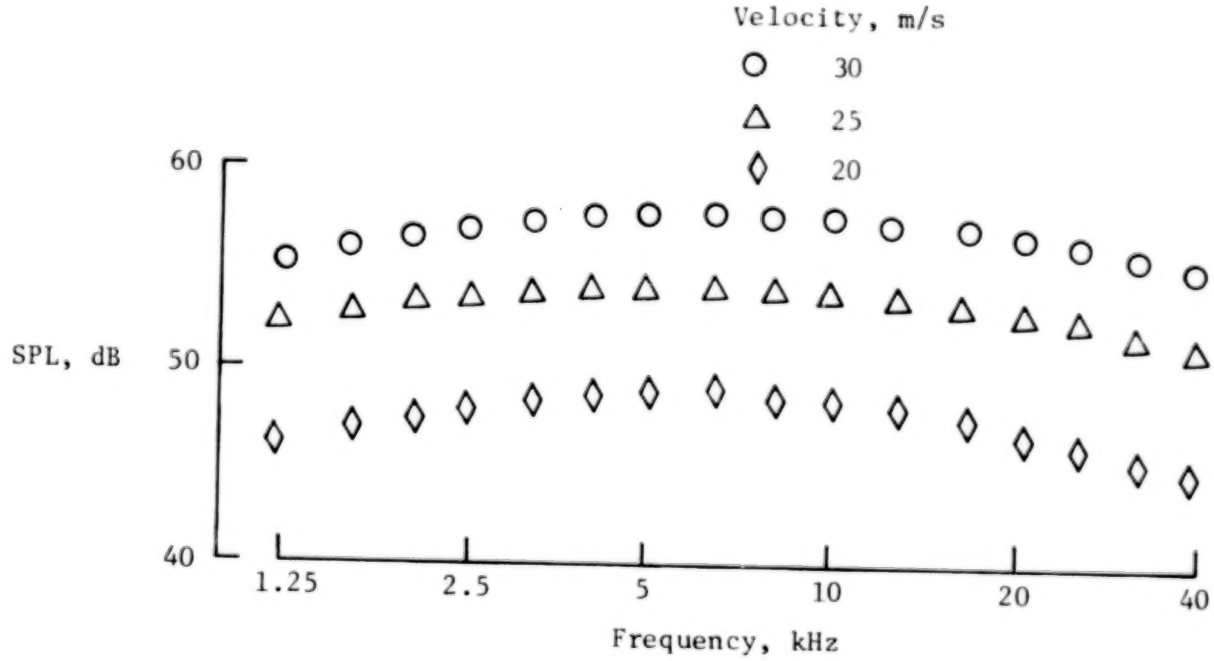


Figure 6.- One-third octave band airframe noise spectra due to model leading-edge flaps for three velocities.

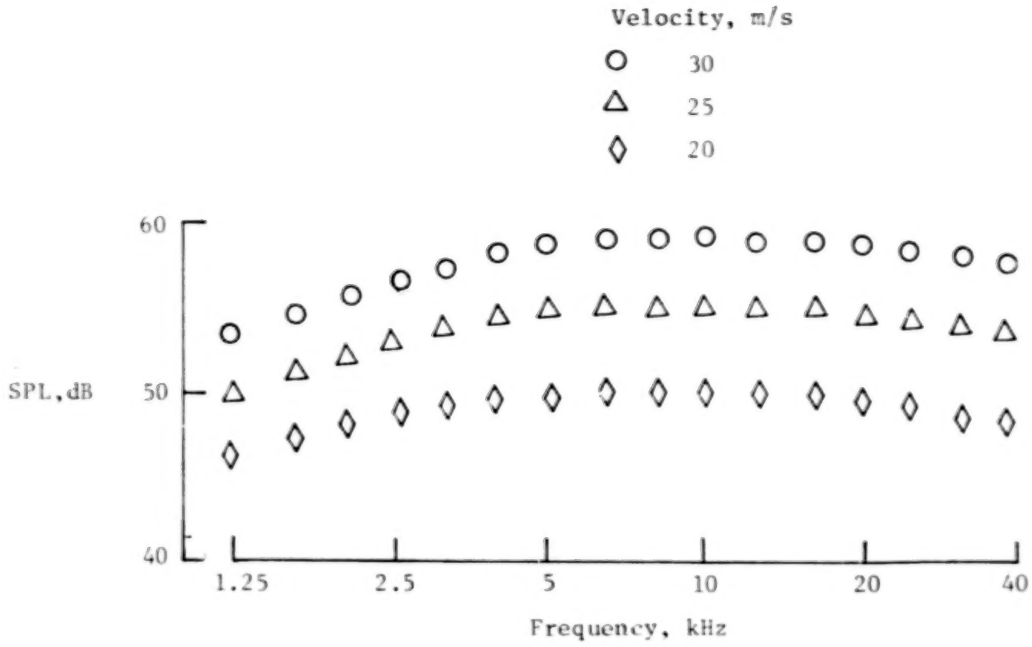


Figure 7.- One-third octave band airframe noise spectra due to model trailing-edge flaps for three velocities.

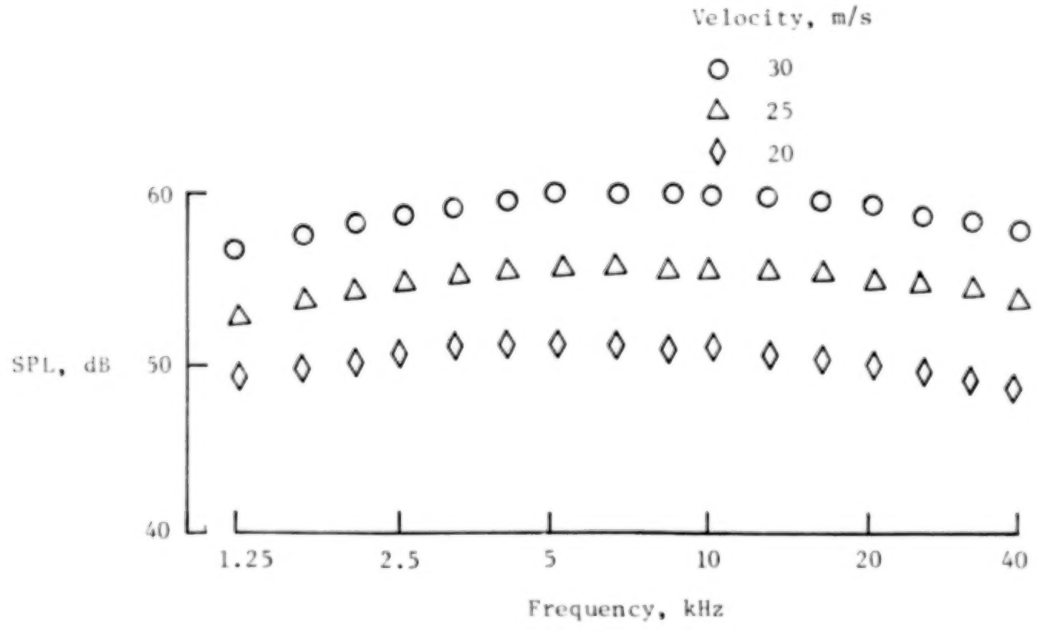


Figure 8.- One-third octave band airframe noise spectra due to model leading- and trailing-edge flaps combined for three velocities.

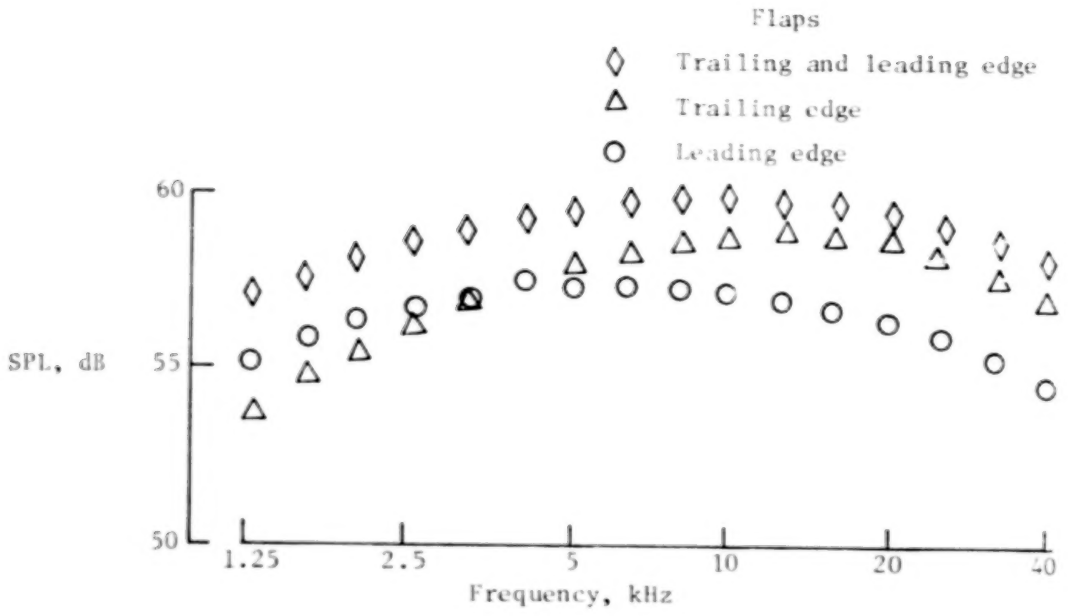


Figure 9.- Comparison of one-third octave band airframe noise spectra due to model individual flap systems at velocity of 30 m/s.

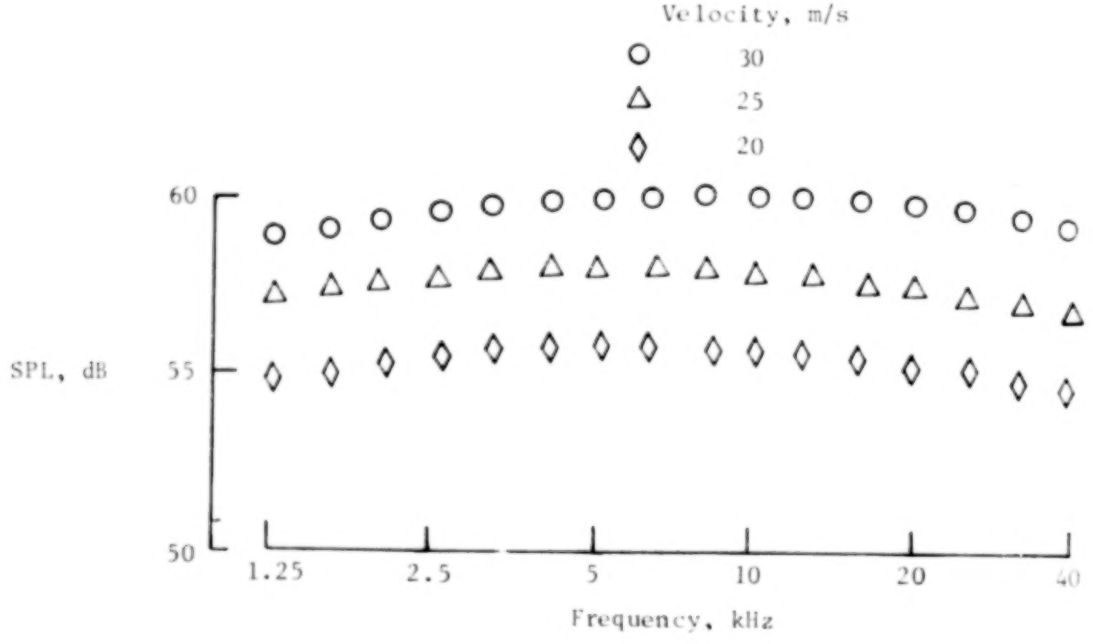


Figure 10.- One-third octave band airframe noise spectra of model in landing configuration for three velocities.

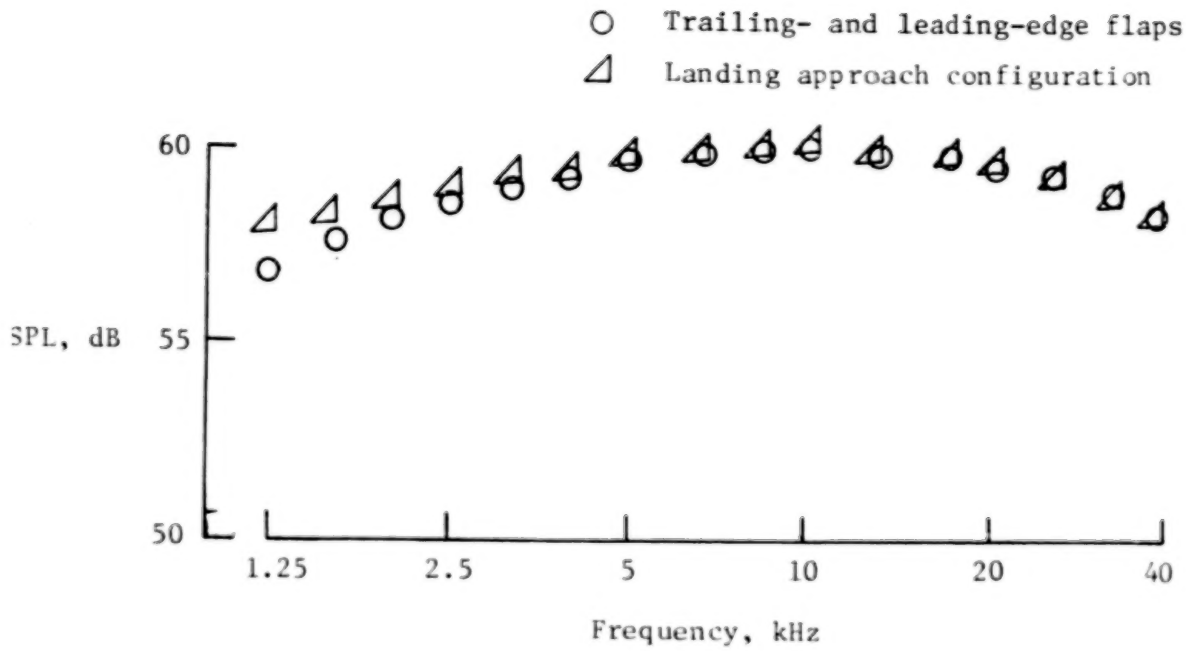


Figure 11.- Comparison of one-third octave band airframe noise spectra with model in landing configuration and with only flap system at velocity of 30 m/s.

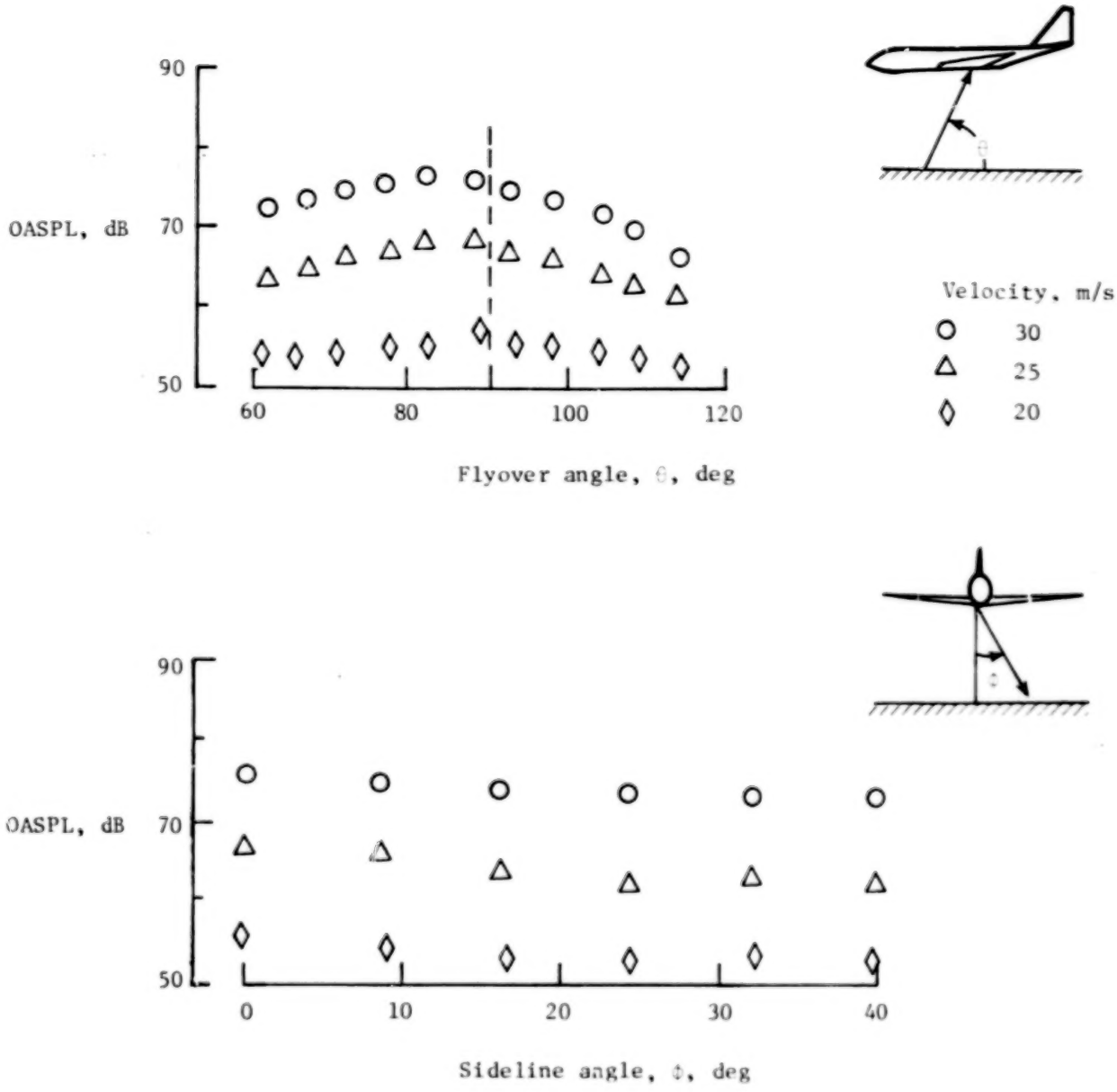


Figure 12.- Directivity pattern in flyover and sideline planes for landing approach configuration.

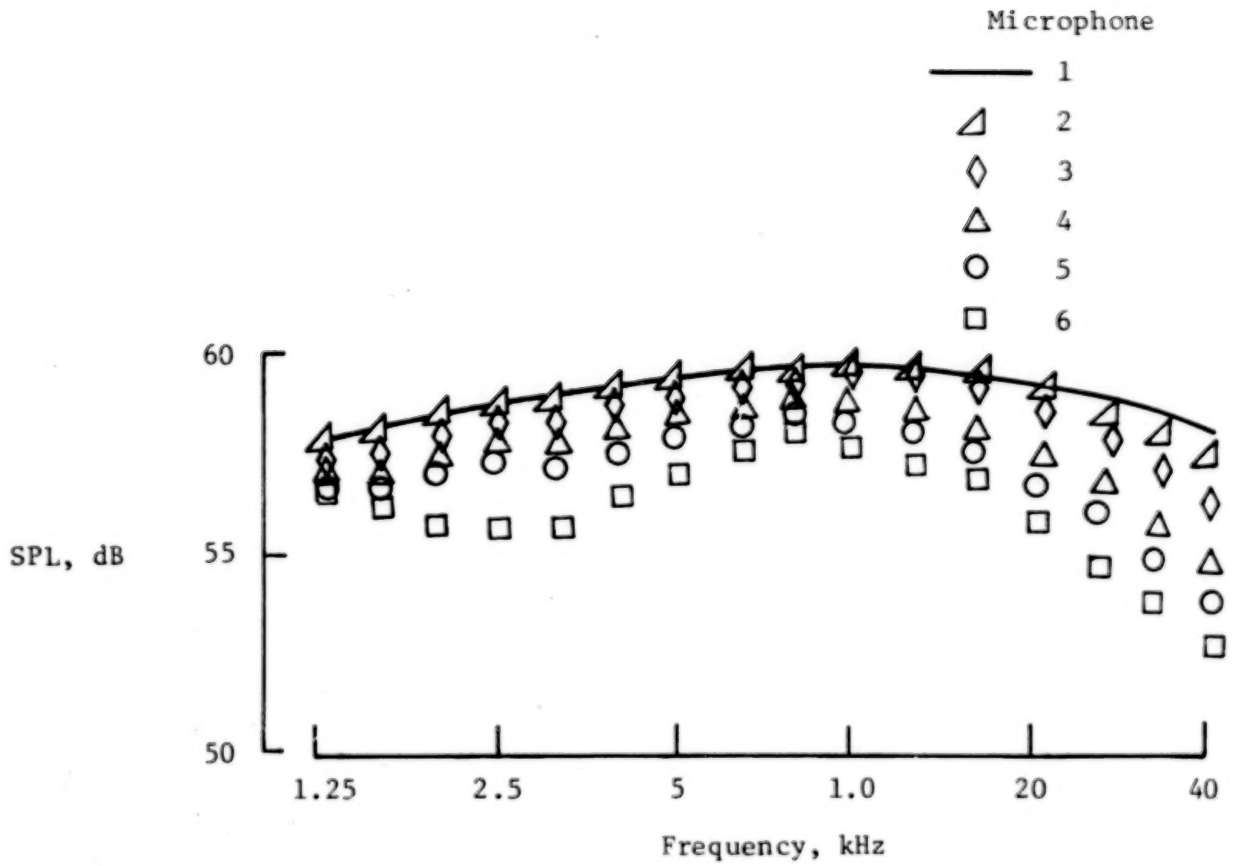


Figure 13.- One-third octave band airframe noise spectra of sideline microphones with model in landing configuration at velocity of 30 m/s.

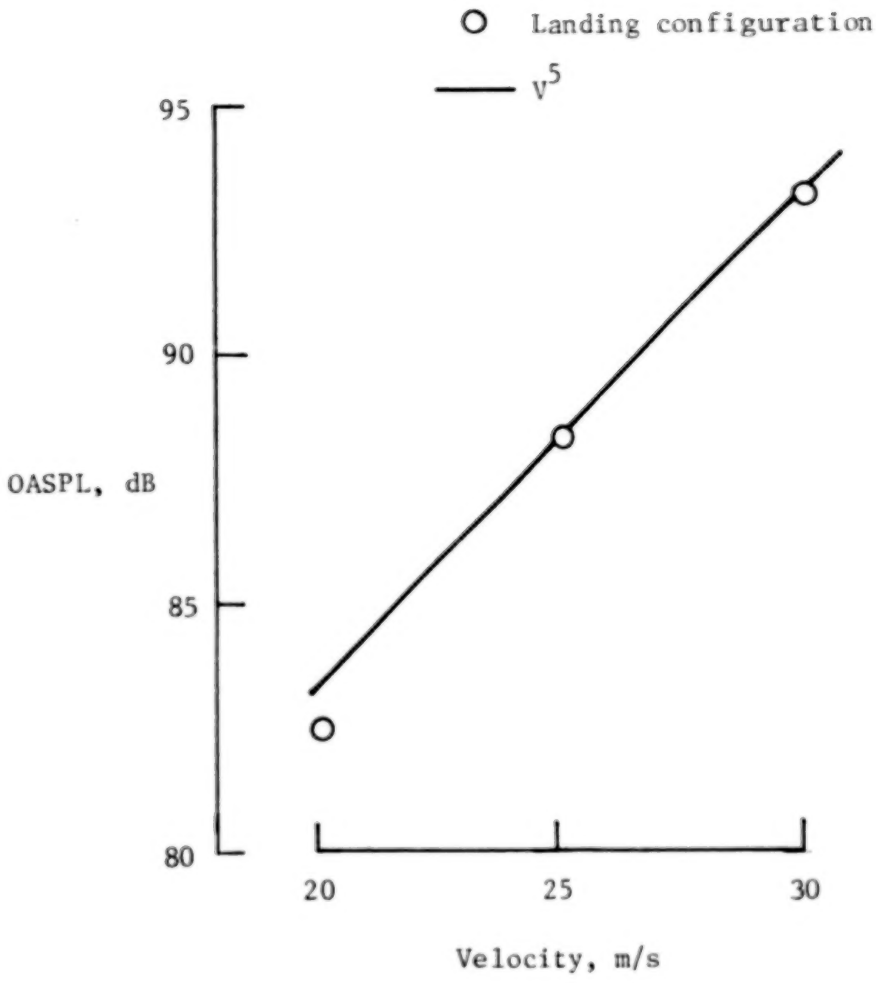


Figure 14.- Variation of overall sound pressure level with velocity, with model in landing configuration and at overhead position.

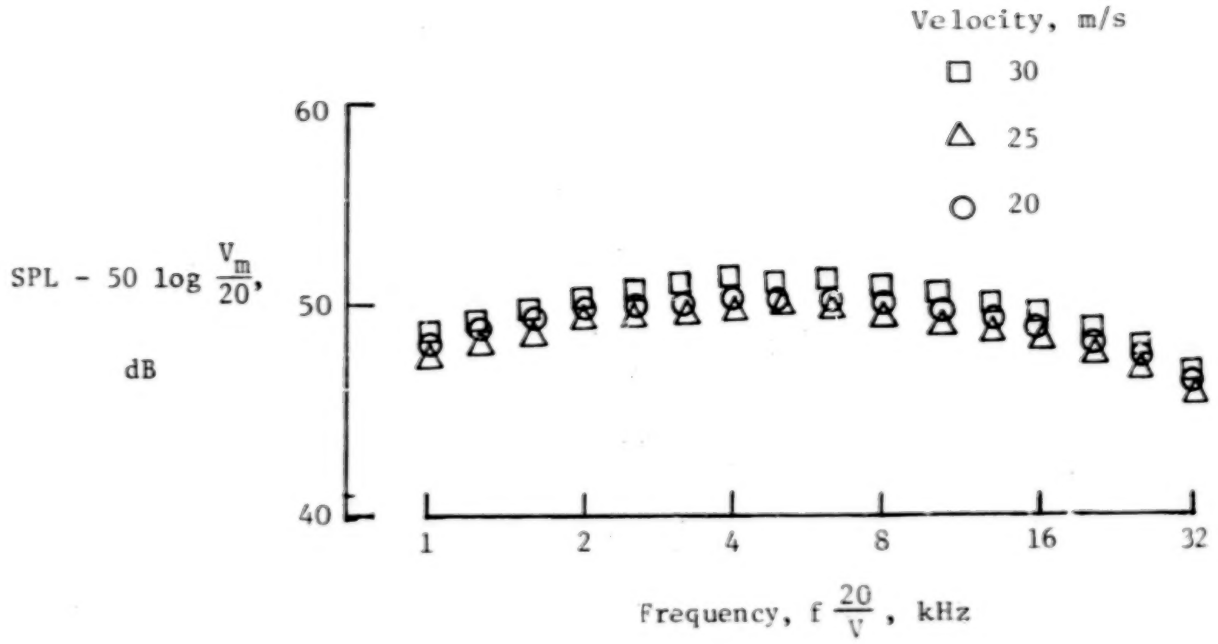


Figure 15.- Model noise data obtained at three velocities and normalized to 20 m/s.

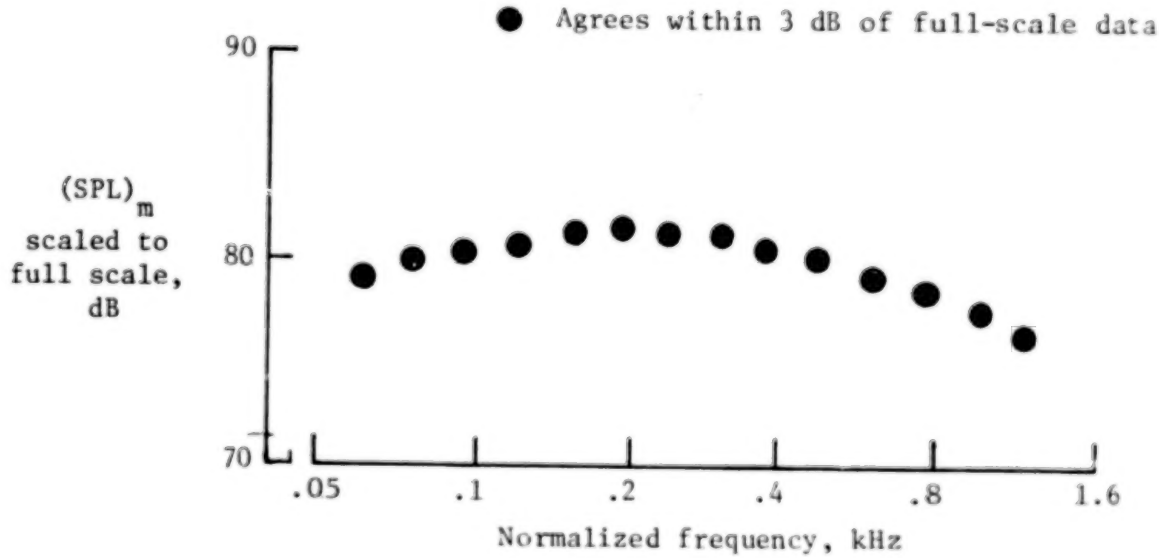


Figure 16.- One-third octave band spectra of sound pressure level of 0.01-scale-model data scaled to full-scale data, for model with leading-edge flaps extended.

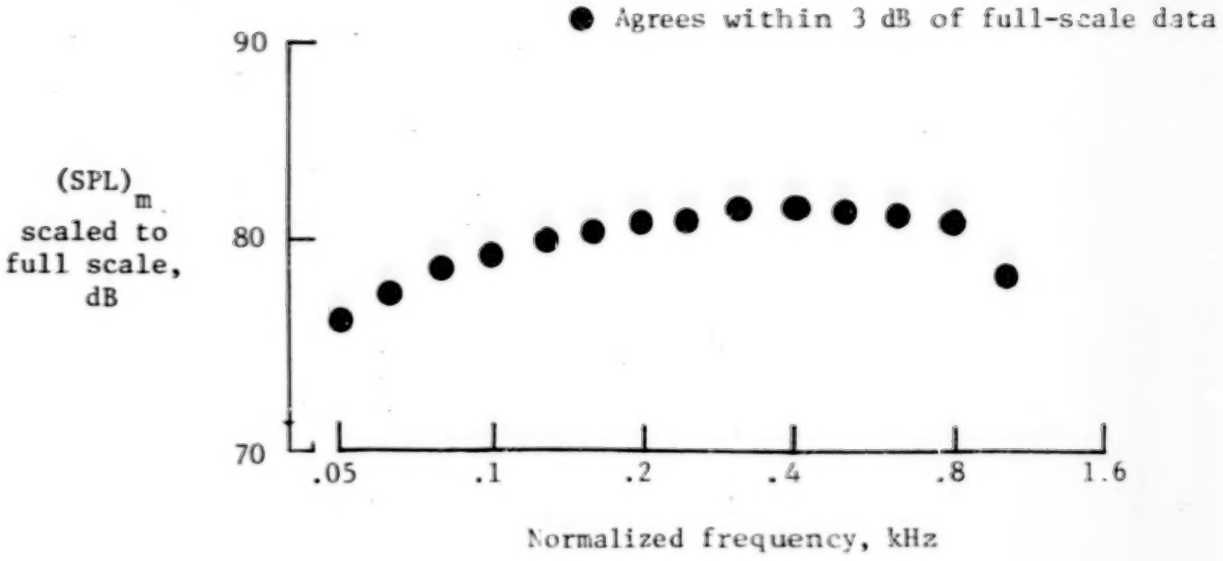


Figure 17.- One-third octave band spectra of sound pressure level of 0.01-scale-model data scaled to full-scale data, for model with trailing-edge flaps extended.

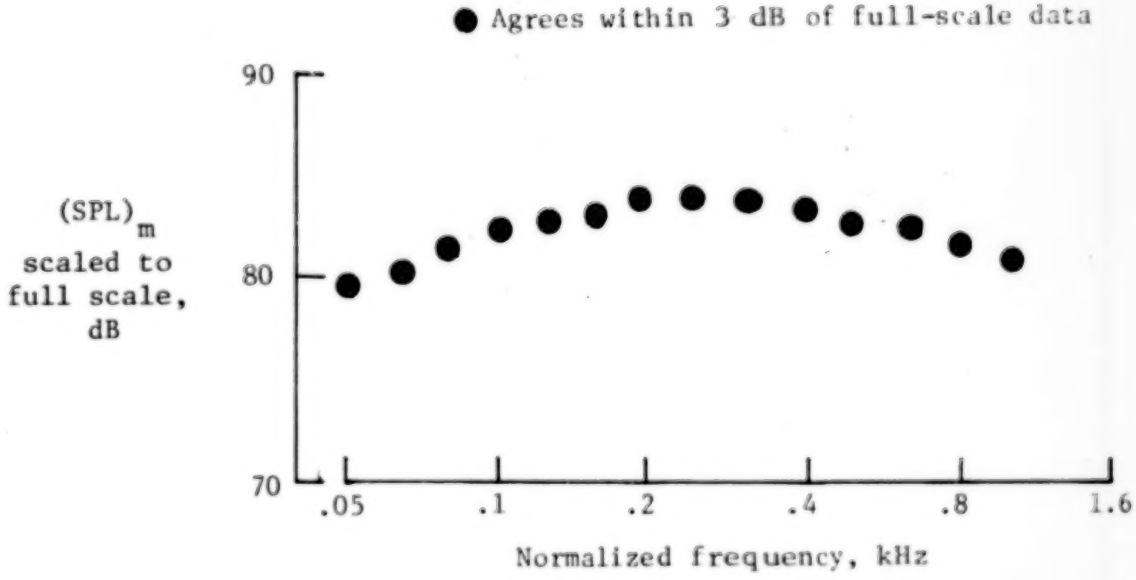


Figure 18.- One-third octave band spectra of sound pressure level of 0.01-scale-model data scaled to full-scale data, for model with both trailing- and leading-edge flaps extended.

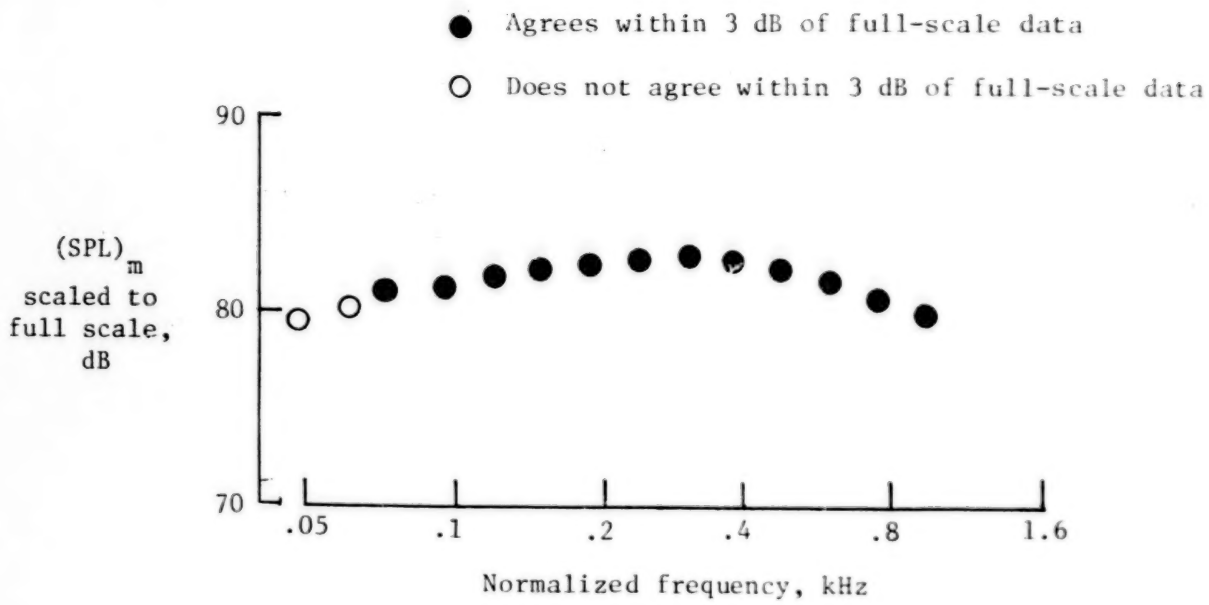


Figure 19.- One-third octave band spectra of sound pressure level of 0.0.-scale-model data scaled to full-scale data, for model in landing approach configuration.

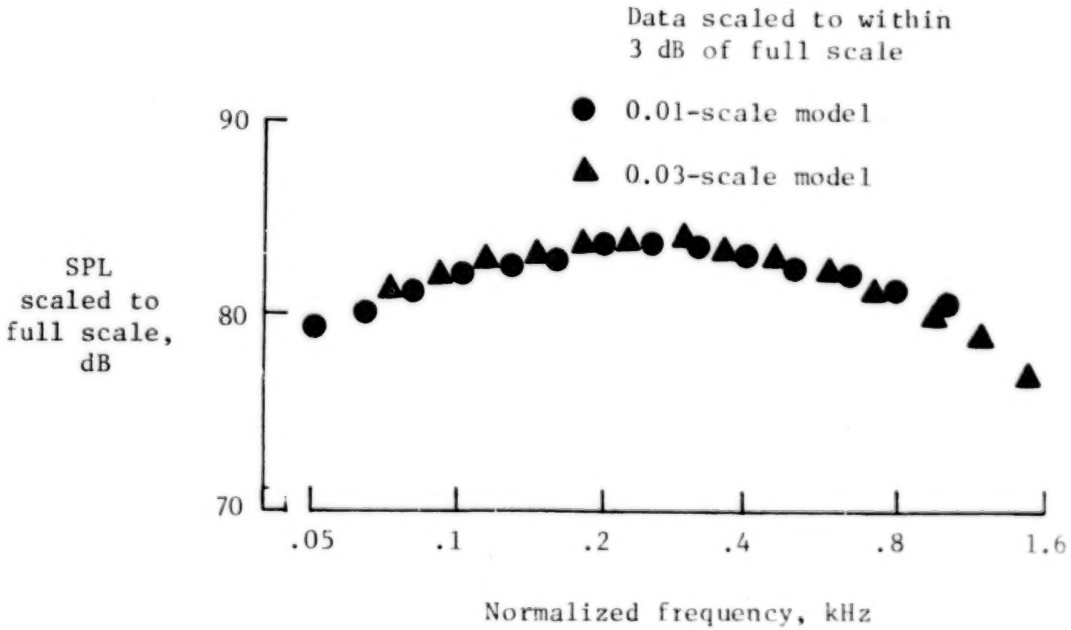


Figure 20.- Variation of one-third octave band spectra of sound pressure level of 0.01-scale- and 0.03-scale-model data scaled to full-scale data, for model with leading- and trailing-edge flaps extended.

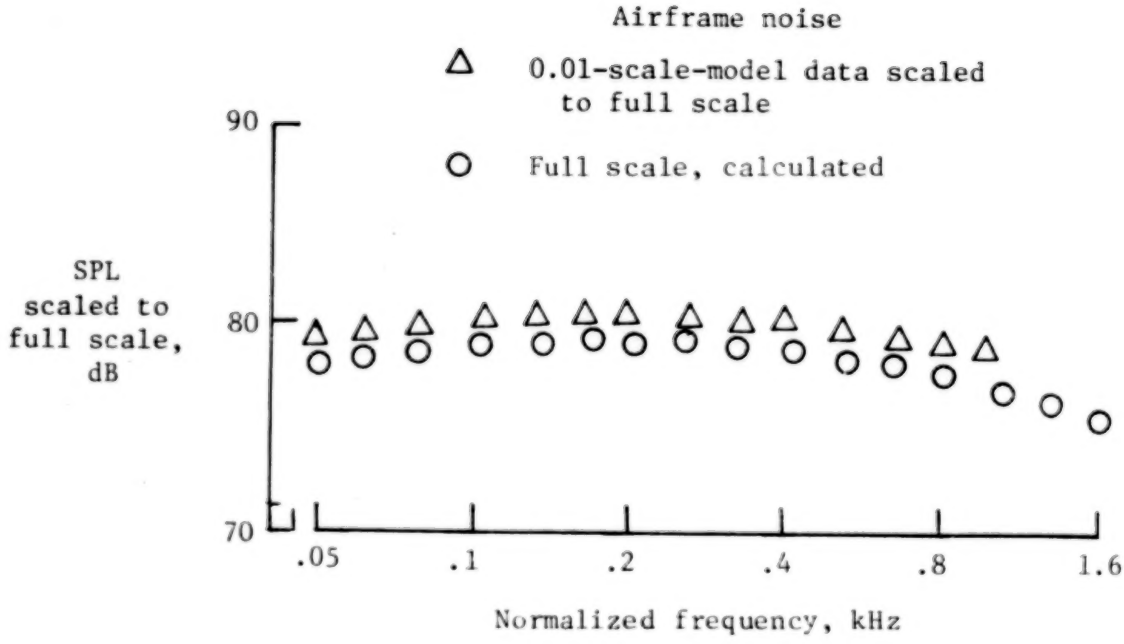


Figure 21.- Comparison of calculated one-third octave band full-scale airframe noise and model airframe noise scaled to full scale at velocity of 30 m/s. Model in overhead position.

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16. Abstract

Airframe noise of a 0.01-scale-model Boeing 747 wide-body transport has been measured in the Langley Anechoic Noise Facility. The model geometry simulated the landing and cruise configurations. The model noise was found to be similar in noise characteristics to that possessed by a 0.03-scale-model 747. The 0.01-scale-model noise data scaled to within 3 dB of full-scale data using the same scaling relationships as that used to scale the 0.03-scale-model noise data. The model noise data are compared with full-scale noise data, where the full-scale data are calculated using the NASA Aircraft Noise Prediction Program (ANOPP).

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